Climate research at the Met Office Hadley Centre

Informing Government policy into the future

"The Met Office Hadley Centre holds a unique position in the world of climate science. No other single body has a comparable breadth of climate-change science and modelling, or has made the same contribution to global climate science and current knowledge."

Independent Review 2007 [1]

"Warming of the climate system is unequivocal... "

"Most of the observed increase in global average temperatures since the mid-20th century is very likely [more than 90%] due to the observed increase in anthropogenic greenhouse gas concentrations."

IPCC[2] AR4 WGI[3] SPM[4]
February 2007

"Like every advanced industrialised country, we are coming to terms with issues surrounding climate change."

Prime Minister Gordon Brown,
July 2007

[1] Independent Review of the Met Office Hadley Centre commissioned from Risk Solutions by Defra and MoD, 2007 - www.metoffice.gov.uk

[2] IPCC Intergovernmental Panel on Climate Change.

[3] 4th Assessment Report Working Group 1.

[4] Summary for Policy Makers.

Introduction

It has been demonstrated beyond reasonable doubt that the climate is changing due to man-made greenhouse gases. We are already committed to future substantial change over the next 30 years and change is likely to accelerate over the rest of the 21st century.

It is therefore vital that more detailed regional climate change predictions are made available both in the UK and internationally so that cost effective adaptation and appropriate mitigation action can be planned. If no action is taken on climate change the costs of adaptation are potentially huge both economically and socially. Well informed investment now and in the future could cut these costs significantly. The best possible scientific advice is an important element of this information.

The new Integrated Climate Programme (ICP) of the Met Office Hadley Centre combines the requirements of Defra[1] and MoD[2] for information on climate change. It provides the science that will be required to help policymakers and other stakeholders in the UK and internationally to deal with climate change in the future. This brochure sets out the key science questions that the ICP will address to underpin government policy and planning.

- How will climate change regionally in the near future?
- What are the risks of dangerous climate change?
- Can we avoid dangerous climate change?
- What are the potential impacts of climate change with different degrees of mitigation and adaptation?

A key focus of the ICP is to quantify and reduce the uncertainties in climate predictions and in our assessment of past climate change in order to improve the information provided to stakeholders.

[1] Defra is the UK Government s Department for Environment Food and Rural Affairs.

[2] MoD is the UK Government s Ministry of Defence.

World-class science

The Met Office Hadley Centre has played a central role in providing the scientific evidence of climate change and man's influence on the climate in order to inform Defra, the MoD and other stakeholders.

Strong collaboration and partnerships with other research institutions nationally (in particular NERC[1]) and internationally have been important to the success of the Met Office Hadley Centre and are integral to the future of the programme in many areas.

"The [Met Office] Hadley Centre has been invaluable in helping us to build a rigorous scientific base for our analysis."

Testimonial from **Sir Nicholas Stern**

Translation of science into policy advice

The UK's draft Climate Change Bill recognises that all aspects of government policy and the UK economy will be affected by climate change. The *Stern Review on the Economics of Climate Change* stated that high-quality information on regional scales will be required to provide a policy framework to guide effective adaptation. The ICP will be a major contributor to the decision-making process by providing relevant and timely climate change predictions.

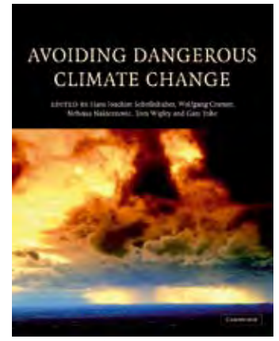
One of the main outputs in the first two years of the ICP will be new climate change scenarios created specifically for the UK Climate Impacts Programme (UKCIP) funded by Defra. Output from Met Office Hadley Centre models will be combined with information from other sources to give improved predictions of future climate. These will be made publicly available in autumn 2008 by UKCIP08 and will play a vital role in enabling the Government, industry and individuals to plan for climate change in the UK. For the first time, the scenarios will provide quantitative advice on the risks of climate change.

The ICP will deliver better climate science for policy and planning. There will be continued participation in IPCC scientific presentations at UNFCCC[2] COP[3] and other international activities. There will also be closer involvement with government via the lead departments (Defra and MoD) through provision of tailored advice. For example, the MoD recently commissioned work on climate change and security. This has already been used by MoD and the FCO[4] for policy and planning.

[1] Natural Environment Research Council.
[2] United Nations Framework Convention on Climate Change.
[3] Conference of the Parties.
[4] UK Government's Foreign and Commonwealth Office.

Major science conference to inform policy

The Met Office Hadley Centre hosted a major international conference on Avoiding Dangerous Climate Change in February 2005 (opened by Margaret Beckett the then UK Environment Secretary) as part of Defra's input to that year's UK presidency of G8.



www.cambridge.org

The economics of climate change

The Met Office Hadley Centre contributed science to Sir Nicholas Stern's quantified risk-based assessment of the costs of mitigation, impacts and adaptation in both the developed and developing world.

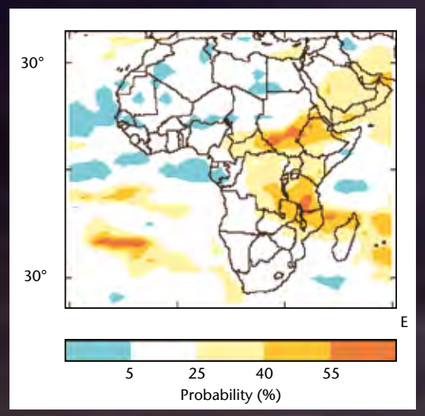
How will climate change in the near future?

Man made climate change means that the past will not be a good indicator for the future. Forecasts for the next season, year and decade will take on a higher priority. In particular, our ability to forecast extreme climate events a season ahead will enable vital short term actions to be taken.

Planners and other users also require information on annual and decadal timescales. The Met Office is unique in providing predictions from daily through seasonal to decadal and centennial timescales using the Unified Model framework.

Forecasting for the next season

Met Office seasonal predictions are provided to government departments, public websites and meteorological services worldwide. The Met Office was one of the first centres to be awarded World Meteorological Organization status as a Global Producing Centre for long range forecasts. These are issued routinely for Europe and the Regional Climate Outlook Forums of Africa and East Asia. Meetings are held in advance of each region s rainy season at which local and international experts input forecasts from numerous sources to form a consensus on the outlook for the region for the season ahead.



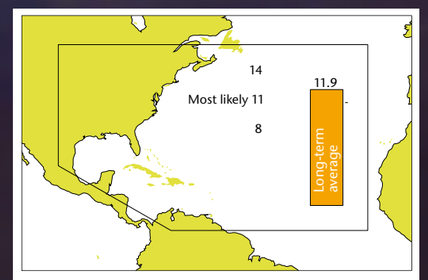
Forecast of low rainfall for October to December, East Africa short rains period, issued in September 2005 from the Met Office seasonal forecast. This low rainfall category has an historic average probability of 20%. The forecast indicated more than 25% probability (yellow/orange shading) over a wide area and more than 40% in some regions (e.g. Tanzania). This provided useful guidance enabling the authorities to avoid the worst consequences of food and water scarcity and disruption to power supply.

One feature of our modelling system is that it has considerable skill predicting the number of tropical storms in the North Atlantic season (usually June to November). For example, the change from the exceptionally active season of 2005 to the below normal activity of the 2006 season was well predicted.

This marked difference between seasons was missed by a number of statistical prediction methods, which have traditionally formed the basis of most published forecasts. Our short range weather forecasts also produced one of the most accurate predictions of the path of hurricane Katrina in 2005. The figure opposite shows a trial seasonal prediction for July to November 2006. Our first operational prediction was issued on 19 June 2007 for July to November 2007. (www.metoffice.gov.uk)

Other key forecasts, with users from around the world, include

- Seasonal probability forecasts for the UK and Europe issued to the public and planners.
- Regional precipitation for tropical NW Africa, E Africa and NE Brazil — regions with high climate vulnerability but also with relatively high forecast skill.
- Specialised forecasts to support MoD operations in Iraq, Afghanistan, Yugoslavia and the Falkland Islands.
- Prototype monthly forecasts of Environmental Stress Index, designed for direct use by MoD personnel, have been trialled for operations in Iraq and Afghanistan and for training activities in the UK.



Tropical storm forecast for the North Atlantic basin July to November 2006. The forecast indicated a 70% chance that the number of tropical storms would be in the range eight to 14, with 11 the most likely number. This represented slightly below normal activity relative to the 1987 2005 long term average of 11.9. Observed activity for the 2006 season was indeed below normal with nine tropical storms observed in the July to November period.

New work

Predictions will be improved by:

- Using the most up to date models and understanding of climate processes.
- Improving the initial conditions for the ocean using new technical developments and more extensive observations.
- New dissemination techniques to provide information in a form useful to users.

The recent drought in Australia has impacted on farming. It has also affected the indigenous animal population.

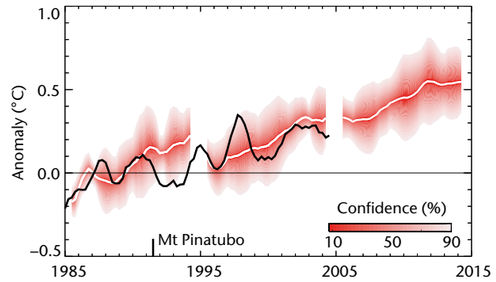
Forecasting the next decade

On a timescale of several decades the prediction of global warming is now robust. However, over the next few years natural variations may either amplify or offset some of the warming. Whilst having predictions of the state of the climate a season ahead allows for some types of adaptation measures to be put in place — such as stockpiling food or sandbags — having skilful predictions up to a decade in advance allows for a greater range of actions including major infrastructure changes such as improved building ventilation or flood protection. The five to 10 year period is also the length of the planning cycle for many businesses.

The Met Office Hadley Centre has pioneered a new system to predict the climate a decade ahead. The system simulates both the human driven climate change and the evolution of slow natural variations already locked into the system. This is possible because the climate takes a long time to respond to some variations. In particular, the state of the ocean has an impact on climate for months and years into the future. In part, this is because it takes a long time for the ocean to heat up and cool down.

By starting this system in the 1980s and comparing the results with observations from the 1990s we have already demonstrated its skill at predicting the global climate. However, a major effect it cannot predict is volcanic eruptions, so the biggest differences between the model and the observations occur following the major eruption of Mount Pinatubo in June 1991.

We are now using the system to predict changes out to 2014. By the end of this period, the global average temperature is expected to have risen by around 0.3 °C compared to 2004, and half of the years after 2009 are predicted to be hotter than the current record hot year, 1998.

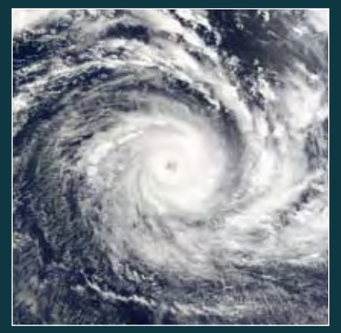


Observations of global average temperature (black lines) compared with decadal 'hindcasts' (10-year model simulations of the past, white lines and red shading), plus the first decadal prediction for the 10 years from 2005. Temperatures are plotted as anomalies (relative to 1979–2001). As with short-term weather forecasts there remains some uncertainty in our predictions of temperature over a decade. The red shading shows our confidence in predictions of temperature in any given year. If there are no volcanic eruptions during the forecast period, there is a 90% likelihood of the temperature being within the shaded area.

New work

The current system captures some aspects of regional change but there are some limitations, for instance, our ability to simulate the North Atlantic Oscillation which affects the European weather and climate. A key aim of our next generation computer model is to improve regional predictions.

Future work will extend the range of outputs, for example, by providing information on changes in extremes, so that stakeholders can obtain maximum benefit from this new type of prediction.



What are the risks of dangerous climate change?

Risk of large changes in ocean circulation and the release of methane clathrates

Risk of significant loss of Amazon rainforest

Globally few ecosystems can adapt, consequent reductions in food supply and further damage to the climate system

Melting of Greenland ice sheet may become irreversible

Some marine ecosystems suffer irreversible change. Ocean acidification is already a risk.

"The ultimate objective of this Convention ...is to achieve ...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

UNFCCC Article 2

Climate science can predict many of the implications and potential dangers associated with various amounts of climate change. The Met Office Hadley Centre has made considerable progress in understanding integrated dangers, where the temperature rise is only one of the environmental stresses leading to local impacts.

New work

Ice sheets
Improved modelling of ice sheets and inclusion of Antarctica as well as Greenland will enable better predictions of sea-level rise and at what stage changes are likely to become irreversible.

Ecosystems
Improved modelling of the interaction between climate and the biosphere will reduce uncertainty in predictions of climate change and consequent changes to the biosphere.

Ocean circulation
The risks will be quantified of a shutdown of the major overturning circulation in the Atlantic which would cause widespread cooling in Europe.

Methane clathrates and permafrost
The likelihood will be assessed of release of methane from vast undersea stores and from thawing permafrost, both of which could greatly enhance climate change.

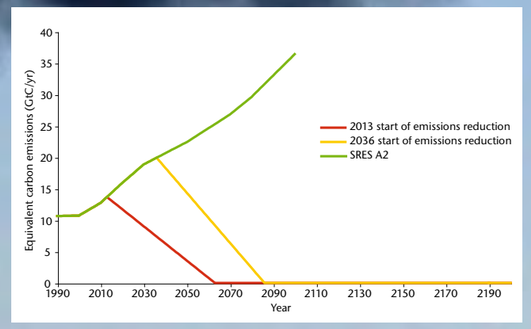
Can we avoid dangerous climate change?

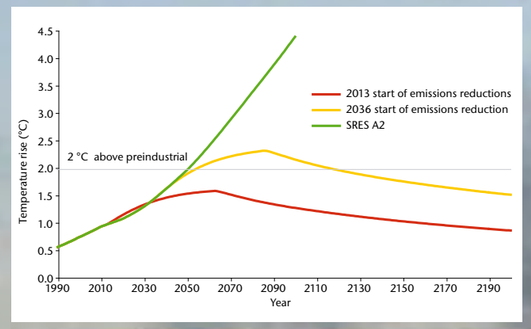
The Kyoto Protocol prescribes limits to emissions of greenhouse gases for some of the world's emitters up to the year 2012. The UNFCCC provides a framework for discussing the further reductions that would be needed to avoid the most significant impacts of climate change. The European Union currently supports the aim of keeping global average warming to less than 2 °C above pre industrial temperatures.

The Met Office Hadley Centre provides advice on the consequences of a range of future emissions scenarios. The figure opposite shows two future scenarios in which greenhouse gas emissions, initially following the IPCC SRES A2 scenario[1], are reduced in the future over 50 years, starting in either 2013 or 2036. These years correspond to equivalent carbon dioxide (CO_2) concentration[2] reaching 450ppm[3] and 550ppm, respectively. The scenarios include the effect of greenhouse gases and sulphate aerosols. The 2036 scenario eventually brings the projected future warming well below that of 'business as usual[4]' but earlier action avoids a further 1 °C of potential warming.

By including our latest estimates of uncertainty in climate response, we have estimated the likelihood of temperature increases of 2 °C and 3 °C above pre industrial levels for a range of potential greenhouse gas stabilisation levels. These represent the eventual temperatures which will take at least several decades to achieve after atmospheric greenhouse gas concentrations are stabilised. This is a consequence of the ocean adjusting slowly to the atmospheric greenhouse gas changes.

If greenhouse gases and aerosols were fixed at today s concentrations then temperatures would continue to rise by between 0.25 and 0.75 °C by the end of the century.





The emissions for the three major greenhouse gases (CO_2, CH_4 and N_2O) expressed as carbon equivalent emissions (upper panel) and the predicted temperature rise for these scenarios.

CO_2 equiv sabilisation level	For 2 °C target	For 3 °C target
430	63	10
450	77	18
550	99	69
650	99	94

Percentage likelihood of eventual warming exceeding 2 and 3 °C temperature thresholds above pre industrial levels

New work

We are now investigating a wide range of future scenarios which include uncertainties from both the climate system and natural ecosystems.

We are also examining the ease with which the climate system and associated impacts can recover if temperature targets are exceeded. Eventually, the results will form part of a new integrated assessment of the effect of mitigation action on climate and resulting impacts.

[1] SRES A2 is a business as usual scenario with medium to high emissions of greenhouse gases and aerosols.
[2] Equivalent CO_2 concentration provides a way to combine the effects of a range of greenhouse gases into a single measure. Some authors also include the effects of aerosol particles. While these are included in our simulations they are not included in our reported equivalent CO_2 concentrations.
[3] Parts per million.
[4] Business as usual' means that emissions of greenhouse gases are not controlled, but continue to grow as economies and populations grow.

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Adaptation and planning

Climate variability already poses a substantial challenge for society and further changes in climate are now unavoidable, even assuming a future international agreement and implementation of mitigation policies. This makes the development of adaptation strategies imperative. We are providing a wide range of scientific information to support these activities.

Adaptation and planning requires good quality information on the risks of climate change and its impacts in a form that is relevant to users. The new Integrated Climate Programme will put the Met Office Hadley Centre in a unique position to integrate climate change information into planning and decision making processes in government and industry and to integrate weather and climate information into contingency planning. Results will cover a range of timescales from seasons through decades to more than a century, and a range of spatial scales from global down to continental and regional scales (for example to give useful information for the UK regions). A particular aim will be to present many of the results probabilistically in order to enable quantified risk assessment as a basis for planning and policy decisions.

It is not just the change in temperature and rainfall that are important, but also more complex effects on the physical and biological environment and on human systems (see opposite). The Met Office Hadley Centre will work with other providers to supply consistent information on the impacts of climate change. Examples of the output will include predictions of extreme events, water availability, coastal flooding and heat stress. One of our main customers, MoD, has commissioned work as part of the programme to assess which sensitive regions of the world are likely to reach crisis point as a result of increased environmental stresses. We will also be able to inform MoD about the climate impacts most relevant to its operations.

New work

Two major initiatives currently being undertaken are the production of a new set of climate scenarios for the UK Climate Impacts Programme in 2008 (UKCIP08), and making available the regional climate modelling system PRECIS (Providing REgional Climates for Impacts Studies) to scientists from developing countries. These will enable stakeholders to obtain the climate information they need in order to understand how changes will affect their interests on a local scale, and to form relevant adaptation plans.

The Met Office Hadley Centre climate models already produce a wide range of impact relevant quantities, including:

- Air temperature
- Rainfall
- Snowfall
- River flow
- Soil moisture and temperature
- Wind speed and direction
- Surface sunlight amount
- Cloud amount
- Ecosystem productivity
- Sea ice amount
- Ocean temperature and salinity

In addition we now routinely produce many derived quantities including:

- Sea level rise
- Heat stress
- Water stress
- Air quality

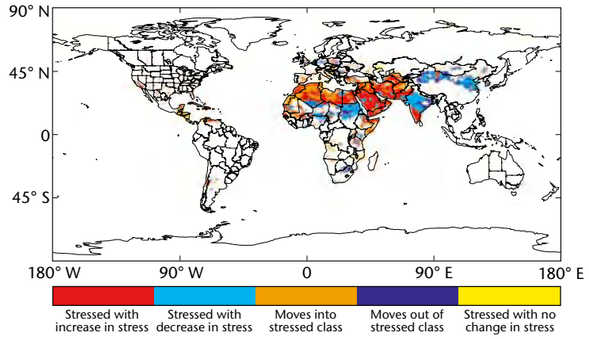
Water - drought and flooding

According to the United Nations Environment Programme, in the mid-1990s about 1.7 billion people lived in water-stressed countries and 20% of these lacked access to safe drinking water. By 2030, assuming a 'business as usual' scenario, population growth alone could almost double this number. In many regions climate change is likely to exacerbate such stresses.

Over half of the world's drinking water is extracted directly from rivers or reservoirs. Our climate model predictions indicate large reductions in river flow across Southern Europe, the Middle East, the Amazon Basin, and the Danube for the 21st century under a 'business as usual' emissions scenario. Clearly, changes of this magnitude could significantly exacerbate water stress in affected regions and, where rivers flow across national borders, foster international conflict. Our current challenge is reducing the uncertainty in these regional predictions.

River, country	% change in flow
Congo, Zaire	30.6
Changjiang/Yangtze, China	19.0
Brahmaputra, Bangladesh	23.3
Ganges, Bangladesh	30.7
Amazon, Brazil	-13.4
Magdalena, Colombia	-23.8
Orinoco, Venezuela	-18.7
Zambezi, Mozambique	-34.9

Over half of the world's drinking water is extracted directly from rivers or reservoirs.



The change in water stress between today and the end of the 21st century for a 'business as usual' scenario. Water stress is defined as occurring when the water availability, in this case river flow, divided by the population is less than 1700 cubic metres per year.

Increases in global temperature are expected to increase evaporation and intensify the water cycle. While this will drive the increase in drought in some locations at certain times, it is likely to increase rainfall in others.

Furthermore, a greater fraction of the rain may fall in very intense events, increasing run-off and flooding in some areas. Recent work at the Met Office Hadley Centre showed that our models are able to reproduce observed changes in drought. The same models project that an additional 30% of the global land mass is likely to experience drought by the end of the 21st century under 'business as usual' conditions. However, the regional details are still very uncertain.

New work

Work is now focusing on estimating the risk of drought and flood events and linking the climate changes to the vulnerability of populations in different parts of the world. This will include accounting for local conditions and water management practices.

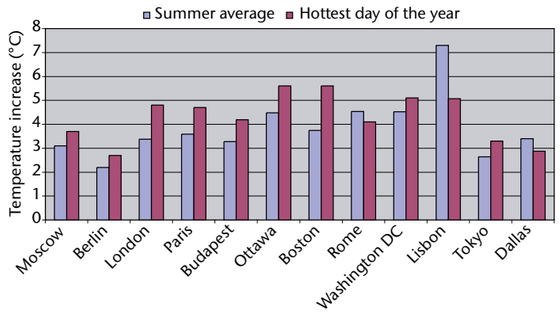
We are also planning to estimate the change in water supply from mountain glaciers, on which around one sixth of the world's population currently depend.

"[The] probability of European mean summer temperatures exceeding those of 2003 increases rapidly under the SRES A2 scenario, with more than half of years warmer than 2003 by the 2040s."

Stott et al., Nature,
2004

Changing temperature extremes and health impacts

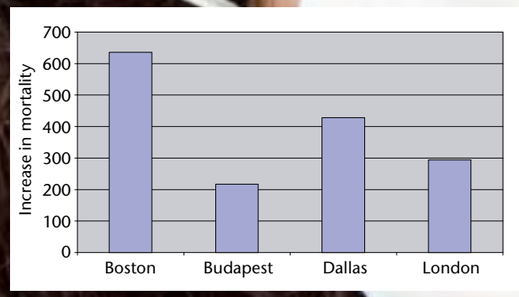
Night-time temperature extremes have already risen as a result of human emissions of greenhouse gases. In the future, this trend is predicted to continue and daytime extreme temperatures are also expected to rise significantly (see figure below).



Projected increases in the summer average temperature and that of the hottest day of the year from a Met Office Hadley Centre global climate model for a range of world cities when the global average temperature increases by 2 °C. In all cases the cities warm by more than the global average temperature.

Temperatures within cities are typically higher than those of the surrounding rural areas due to the release of heat from local power consumption and the way that the urban environment alters the transfer of heat and moisture between the ground and atmosphere. How this urban heat island effect will change in the future is uncertain and will depend on the future size and design of cities.

Without adaptation, future extremes of temperature are expected to increase human mortality, especially when they are sustained for an extended period. Using relationships between past changes in mortality and observed temperature, an estimate of future heat-related mortality can be made (figure opposite). By adapting infrastructures and behaviour to better cope with higher temperatures it should be possible to reduce these potential casualties.



The percentage increase in heat related mortality[1] due to predicted temperature increases for four major cities.

[1]The temperature mortality relationships were derived by a Met Office CASE student, S. Gosling, working at King s College, London.

New work

A key aim of this work is to provide an early warning system of future casualties for health planners. The Met Office already produces short-term health warnings based on weather forecasts and new work will extend the advanced warning time using seasonal and climate change predictions. Long-term predictions including the impact of adaptation measures will be especially useful to planners involved in developing the future health infrastructure.

The Met Office Hadley Centre will also examine the effect of other factors, such as air quality, on human and animal health. We already predict changes in low-level ozone and particulates and this will form a starting point for the new research.

"It is beyond dispute that the Met Office Hadley Centre occupies a position at the pinnacle of world climate science, and in translating that science into policy advice."

Independent Review,
2007

The provision of world-class science to underpin policy

Advice from the Met Office Hadley Centre is based on more than a quarter of a century of climate research focused by strong customer engagement. The Met Office started research on climate in the 1970s. By the end of the 1980s there was an established programme of work on climate modelling, monitoring and seasonal forecasting in addition to the Met Office's core programme on short term weather forecasting. Building on this expertise, the Met Office Hadley Centre was formally opened in May 1990 as the UK's national centre for climate change research.

A key factor in the success of the Met Office Hadley Centre is its approach to modelling. Since the late 1980s, the Met Office has developed a Unified Model for weather forecasting and climate prediction, spanning all timescales from less than a day, through seasonal and decadal to centuries. This enables the sharing of resources for model development and means that weather forecasting tools and results can be used to test and improve the climate model and vice versa.

The Met Office Hadley Centre continues to be at the forefront of climate science. For example, it was a major contributor to all four IPCC Assessment Reports. For the latest report in February 2007, Met Office Hadley Centre scientists played a prominent role in Working Group I *(The Physical Science Basis)*, with eight lead authors, two review editors and numerous contributing authors.

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Key Met Office Hadley Centre results reflected in the report are:

- New observational analyses (with information about analysis error), including global and regional surface temperature changes, extremes and temperature changes in the atmosphere.
- Detection and attribution of climate change on all continents (except Antarctica where data coverage is limited) and in many aspects of climate change, including ocean warming, sea ice, temperature extremes and wind patterns.
- Risk based estimates of climate change.
- Observationally constrained estimates of climate sensitivity[1], which contributed to the new assessment of its range of uncertainty.
- Improved calculations of the impact of aerosols (such as sulphate particles from power stations) on radiative forcing.
- Contributions of ice sheets to sea level change and vulnerability of the Greenland ice sheet to global warming (including the new threshold for irreversibility of 1.9 4.6 °C).
- Better understanding of the ocean circulation and the possibility of weakening the Atlantic Meridional Overturning Circulation.

The Met Office Hadley Centre also hosted the technical support unit for the Working Group II of the IPCC 4th Assessment Report, which provides one of the most complete assessments so far of the impacts of climate change.

[1] The eventual increase in global average temperature if CO_2 is doubled.

"The Met Office Hadley Centre has the highest concentration of absolutely outstanding people who do absolutely outstanding work, spanning the breadth of modelling, attribution, and data analysis, of anywhere in the world."

Dr Susan Solomon,
Co Chair IPCC AR4 WGI

Improving prediction

Uncertainties in climate prediction have major implications for decision-making on both mitigation and adaptation. Under-predicting the future warming may lead to inadequate action being planned and thus greater impacts than anticipated. Over-predicting the warming might be just as costly if adaptation solutions are needlessly over-engineered. Improved predictions will enable spending to be targeted more effectively.

Improving the quality and accuracy of predictions and quantifying the remaining uncertainties are key aims of the underpinning science of the ICP.

Over the next five years we will do this by:

- Improving our knowledge of past climate change and its causes.
- Using this knowledge to constrain future predictions.
- Improving our understanding and modelling of the most important processes for climate change.
- Providing better information on regional details, changes in extreme weather and the impacts of climate change.
- Providing more robust detailed predictions on seasonal to decadal to centennial timescales, incorporating both man made climate change and natural climate variability.
- Developing and using a range of climate models with different properties designed to address different types of questions.
- Improved methods for quantifying uncertainty and translating that information into risk assessment.

New work

The ICP will continue to improve its set of computer models, in particular by incorporating earth system processes (such as the interaction of climate with the biosphere) and in extending weather forecasting techniques to longer timescales.

To remain at the forefront of climate research, the programme will require improved supercomputing facilities, enabling more detailed and complex versions of the Unified Model to be used for a wider range of cases.

Leaders of science at the Met Office Hadley Centre

John Mitchell
Director of Climate Science

Chris Gordon
Deputy Director of Climate Science - with particular responsibility for developing science and collaboration strategy

Vicky Pope
responsible for negotiating the research agreement with Defra and MoD and ensuring it is delivered to a high standard

Derrick Ryall
responsible for the day to day management of the climate programme

Olivier Boucher
leads earth system science and modelling

Chris Folland
leads climate monitoring and detection and seasonal forecasting

James Murphy
leads climate prediction including quantifying uncertainty

Cath Senior
leads climate model development and understanding climate change

Richard Wood
leads climate, cryosphere and ocean research

Jean Palutikof
Head of the Technical Support Unit for IPCC WGII

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